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HUDSON RIVER WATER ---ITS CHARACTERISTICS AND TREATMENT

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HUDSON RIVER WATER—ITS CHARACTERISTICS AND TREATMENT

Richard Hazen,[1] M. ASCE

INTRODUCTION

The Hudson River ranks 24th among the rivers of the United States and 12th among the rivers east of the Mississippi in respect to mean flows. The Hudson River has a drainage area of 13,370 square miles at its mouth, and an average discharge in excess of 20,000 cubic feet per second. However, in spite of this flow and the proximity of many cities of considerable size, the Hudson River is used as a source of water supply to only a limited extent, except for condenser cooling. This limited use may be attributed to three important factors:

1) The river is tidal as far as Troy, and the water has been brackish as far upstream as Poughkeepsie in years past.
2) Some parts of the river are subject to heavy pollution by municipal sewage and industrial waste.
3) Development of relatively pure upland sources has been possible at reasonable cost.

The lack of control over the quality of raw water and the availability of upland supplies led to the abandonment of early Hudson River supplies at Hudson, Catskill and Albany. Today the principal municipal supplies taken from the Hudson River are at Waterford, Rensselaer and Poughkeepsie. The Mohawk River is used at Cohoes.

The purpose of this paper is to assemble data indicating in a general way the quality of Hudson River water and the method of treatment used at several existing plants. The paper is not a brief for the Hudson River as a source of supply for New York City or any other municipality. Many factors other than the raw water quality and feasibility of treatment are involved in selecting the most satisfactory and economical source of supply. Some of these factors would apply only to a major undertaking, others to both large and small works. As potential reservoir sites are built up and the development of upland sources becomes more expensive, the Hudson River will almost certainly receive increasing consideration as a source of supply for both municipal and industrial purposes. At a time when state chambers of commerce, public utility companies and railroads are advertising to the business world the availability of good water supplies across the country, it seems worth while to summarize some of the pertinent features of one of the largest remaining water supply sources in the East.

Description of River and Drainage Basin

The Hudson River flows south from its source, Tear of the Clouds, a small lake in the Adirondack Mountains, for a distance of 300 miles to discharge

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into the Upper Bay at New York. The Mohawk River, much the largest tributary of the Hudson, flows easterly from the central part of the state and joins the Hudson just above Troy. The total drainage area above Troy is approximately 8,100 square miles: 4,600 square miles tributary to the upper Hudson River and 3,500 square miles tributary to the Mohawk River. The drainage area of the lower Hudson River between Troy and Bear Mountain Bridge is approximately 4,600 square miles, making a total drainage area to that point of 12,700 square miles. The lower stretch of the Hudson River between Bear Mountain and New York City cannot be considered a feasible source of fresh water.

The extent of the Hudson River and its drainage area is indicated in Figure 1. The river is unusual in that nearly all of the drainage area lies within one state. It will be noted that the upper Hudson drains the Adirondack Mountains on the west and a small portion of Vermont on the east. The Mohawk River drains the southern slope of the Adirondacks and the wide belt of rolling country between the Adirondacks and the Catskill Mountains to the south. The lower Hudson is fed by tributary streams draining the Berkshires on the east and the Catskill Mountains and Hudson Highlands on the west. The river itself lies in a fairly wide rolling valley to a point just below Newburgh, where it cuts through a narrow rocky gorge about 10 miles long before discharging into the upper end of Haverstraw Bay.

The circled numbers refer to sampling stations in the New York State Health Department surveys of Hudson River water quality in 1949 and 1951, discussed later in this paper.

The emergency Hudson River pumping station of New York City takes water from the river at Chelsea and discharges into the Delaware Aqueduct, which crosses the river at that point. The station has been operated briefly each month for maintenance purposes but the total amount of river water pumped has been negligible. Under the Hudson River plan to augment New York City's supply, proposed by the Engineering Panel on Water Supply in July, 1951, an intake would be located at Hyde Park.

The profile along the main river channel is shown at the bottom of Figure 1. From this it will be noted that most of the river channel is 50 feet deep, or more, except above Catskill where it reduces to approximately 25 feet. The upper part of the river has been dredged from time to time in order to maintain a suitable channel for navigation. Opposite West Point the river reaches a maximum depth of nearly 200 feet. The width of the river varies considerably. At Haverstraw Bay below Peekskill it is approximately 3 miles wide, and in the narrow cut near West Point it is only 1,400 feet wide. At Poughkeepsie the river has a width of 2,400 feet, and at Albany 600 feet.

The Hudson River is used extensively for navigation between New York and Troy, and a lock is provided at Troy to permit barges to move upstream through the Mohawk River to the New York State Barge Canal and up the Hudson River to a small canal connecting with Lake Champlain. Further dredging of the upper river below Albany to provide a deep-water channel has been proposed and may be carried out in years to come. Below Catskill the channel is naturally so deep that changes in the lower reaches of the river are unlikely.

The population of the Hudson River basin above Bear Mountain in 1950 was approximately 1,620,000, which is equivalent to 130 persons per square mile of drainage area. The heaviest population concentration is along the Mohawk River, where in addition to Amsterdam, Utica and Rome, there are many small industrial communities. The three cities near the junction of the

Hudson and Mohawk Rivers—Albany, Troy, and Schenectady—have a total population in excess of 300,000; and 15 other communities of 10,000 population, or more, account for over 450,000 persons.

While the relatively large flows of the Hudson and Mohawk Rivers are not used for water supply purposes, they are used extensively for sewage and waste disposal. Sewage treatment plants have been built at a few of the upper cities, but in general the facilities are entirely inadequate at the present time. At some cities, such as, Albany, Schenectady and Glens Falls, additions to existing works are needed. At others, such as, Utica, Amsterdam, Troy, Poughkeepsie and Newburgh, no sewage treatment is provided and new plants are required.

Even less has been done with the treatment of industrial wastes. Except for some of the dairies and a few isolated industries, there are practically no industrial waste treatment facilities along the Hudson and Mohawk Rivers. Since there are more than 150 separate industries producing a variety of products, such as, machinery, carpets, textiles, leather, gloves, paper and copper products, it is evident that the industrial waste load is substantial. Stream conditions are bad in some places, and without the dilution provided by large flows, they would be intolerable in many stretches of the river.

New York State is presently engaged in a stream classification program and measures to reduce most of the pollution undoubtedly will be taken within the near future.

Hydrology

The flow of the Hudson River has been gaged by the U.S. Geological Survey at Green Island just above Troy since 1946, and there are long-term records for several gaging stations further upstream on both the Hudson and Mohawk Rivers. Below Troy many of the tributary streams are gaged, but there are no discharge records for the Hudson River itself. Flows in the lower Hudson River therefore must be calculated from the estimated unit runoff per square mile of drainage area. While it is recognized that the total discharge of the Hudson River at Bear Mountain may be 50 per cent greater than at Troy, the flows at the Green Island gage are used throughout this paper to indicate the seasonal variations in discharge and their relations to water quality. The discharge at Green Island prior to 1946 has been estimated by combining the records for the Mechanicville gage and the Mohawk River gage at Cohoes.

The mean annual flow and the 5-year running averages of the Hudson River at Mechanicville since 1887 are plotted in Figure 2. Since the gage was established, the river flow has averaged approximately 7,400 c.f.s. or 4,800 m.g.d. In 1931, the driest year of record, the discharge averaged 4,200 c.f.s. at Mechanicville. The Mechanicville record is included primarily to indicate that although there have been cycles of relatively low and high runoff, there is no evidence to support the often-heard statement that the quantity of water available is constantly declining. This is not true, in the upper Hudson at least.

Figure 3 is a frequency plotting of the monthly flows at Green Island for the period 1930-1951, inclusive. It will be noted that the average flow at Green Island is nearly 10,000 c.f.s. and that even in extremely dry months the average flow has been 2,500 c.f.s. or more.

The flows of the Hudson River are regulated by a number of small power dams above Troy and by releases from Indian Lake and Sacandaga Reservoir. Indian Lake Reservoir, with a capacity of 34 billion gallons and a drainage

area of 131 square miles, was built in 1898. It is used for regulating flows through the several hydroelectric plants on the upper Hudson River. Sacandaga Reservoir is owned and operated by the Hudson River Regulating District, an agency of the State of New York. The reservoir was completed in 1930. It has a total capacity of 283 billion gallons and impounds the runoff from a drainage area of 1,044 square miles. The reservoir was built as a multi-purpose project for flood control and river regulation. The cost has been financed entirely by assessment of the various municipal and industrial beneficiaries. Much of the cost has been paid by public utilities and industrial concerns on the basis of increased hydro power derived from the regulated river flows.

An indirect benefit of the Sacandaga Reservoir has been the improvement of water quality by the release of diluting water from the reservoir during periods of low flow. The effect of releases from Sacandaga Reservoir, and to a less extent from Indian Lake, on the low flows at Green Island during the dry summer of 1949 is illustrated in Figure 4. In the latter part of August more than half of the total discharge at Green Island was due to releases from Indian Lake and Sacandaga Reservoirs. The sharp drop in releases at 7-day intervals is due to the fact that power requirements are low over the weekend, and therefore releases from Sacandaga are cut off on Sunday. This weekend regulation, coupled with additional regulation at the hydroelectric plants along the river, sometimes affects unfavorably the water quality immediately downstream.

There are many streams discharging into the lower Hudson River, but none of these are of large size, comparable to the Mohawk River. The largest tributary in the lower Hudson basin is the Wallkill River with a drainage area of more than 800 square miles, which flows from New Jersey northeast into the Hudson near Kingston. Esopus Creek and Roundout Creek in the Catskill Mountains have been impounded by the City of New York for water supply purposes. The total area impounded, including the Schoharie River, which flows north into the Mohawk River, is 666 square miles. Similarly, the Croton River with a drainage area of 375 square miles in Westchester and Putnam Counties has been developed by New York City for water supply purposes. While these two major water works developments have an estimated safe yield of 1,012 m.g.d., they are small in relation to the mean flow of the Hudson River.

The Hudson River is tidal to the lock and dam at Troy. The tidal range varies throughout the length of the river because of characteristics of the river channel and other factors governing tidal flow. The mean tidal range is 4-1/2 feet at the Battery in New York City, reaches a minimum of 2-1/2 feet just below Newburgh, and is approximately 3-1/2 feet at Albany. Tidal effects in the portion of the river above Poughkeepsie are sometimes masked by flood flows. The improvement of the navigation channel between Catskill and Albany in years past has increased the tidal range at Albany by 1 foot and has lowered substantially the plane of mean low water. This has created some difficulty with water intakes at Albany.

The tide is of primary importance in any consideration of the lower Hudson as a source of water supply. The tide not only causes salt water intrusion upstream but also affects the sanitary quality of the water by the back-and-forth motion imparted to the body of fresh water beyond the limits of salt water intrusion. Studies of New York Harbor have shown that the salt water brought into the harbor by the tide is approximately twice the mean flow of fresh water from the Hudson River. At times of high river discharge, the

fresh water barrier keeps the sea water near the outlet. During periods of low river discharge, the salt water is forced many miles upstream. The extent of salt water intrusion is a function of channel dimensions, river discharge, tidal heights, water temperature and density, wind effect, and other factors. Fortunately, the highest tides at New York have occurred in the winter and spring more frequently than in the summer, when river discharges are relatively low.

A factor of considerable importance is that the Hudson River channel is already deep enough for navigation purposes for many miles upstream, and there is no likelihood of channel improvements in the lower river. Therefore, as long as river discharges are maintained as in the past, it is safe to assume that the salt water intrusion will continue to follow the pattern of the past. In this respect the Hudson River differs from many coastal rivers where salt water intrusion has been aggravated by the dredging upstream of progressively deeper navigation channels.

Water Quality

The data on water quality have been obtained from water plant operating records at Poughkeepsie, Waterford and Rensselaer (the Winthrop-Stearns Inc. plant), from New York State Health Department records, and from exhibits filed by the City of New York at hearings before the Water Power and Control Commission. These hearings were held in regard to the City's applications for an emergency supply from the Hudson River at Chelsea in 1949 and for proceedings with the Delaware River development in 1950. The water quality data are not as complete as desirable and in some instances extend over only a short period. However, enough illustrative data are included to give a fair picture of water quality to be expected in the Hudson River. Data regarding salt water intrusion will be presented first, followed by a consideration of the chemical, physical and bacteriological quality of the water.

The chlorides in the upper Hudson River water not subject to sea water intrusion average less than 10 p.p.m. Concentrations greater than this, except possibly near discharges of industrial waste or sewage, indicate penetration of sea water from New York Harbor and the lower river. In a paper "Tidal Phenomena in the Harbor of New York," Transactions A.S.C.E. Volume LXXVI, 1913, page 1979, H. deB. Parsons presented data showing the extent of fresh and salt water mixing in the New York Bay, and the Hudson River as far as Tarrytown. In this paper the term "land water" was applied to water having less than 300 p.p.m. of chlorides. The average percentage of "land water" found at the surface of the river off Tarrytown increased from 85 per cent in January to between 97 and 100 per cent from February through May, and then declined to 80 per cent in July and 73 per cent in November. While the concentration of "land water" at the surface probably was greater than at some depth, it is evident from these data that even as far south as Tarrytown, the water is relatively fresh during periods of high spring runoff. As shown in Figure 2, the annual runoff of the Hudson River at Mechanicville during 1909, when these salinity studies were made, was about average. These data are not presented to suggest that a water supply could be taken safely from the Hudson River as far south as Tarrytown. They are included only to show that during the spring runoff, much of the salt water is forced out through New York Harbor, and that the river is at times relatively fresh within 25 or 30 miles of New York.

The chloride measurements at the Poughkeepsie water works over many

years have demonstrated that under present conditions, Poughkeepsie represents closely the safe lower limit for the full-time use of Hudson River water. Much of the time the water is fresh many miles further downstream, and salt-free water could be obtained from these lower points on an intermittent basis. When the emergency Hudson River pumping station was installed by New York City at Chelsea, it was recognized that if this station were used during periods of extremely low runoff, the chloride content of the water might be higher than desirable.

The Poughkeepsie water works has been in operation for more than 80 years. In that period there have been several occasions when the water was brackish, but only for a few days at a time. The maximum chloride content reported is 300 p.p.m., and in 1930, the year Sacandaga Reservoir went into operation, a maximum chloride content of 188 p.p.m. was reached. The maximum monthly average in 1930 was 41 p.p.m. Since 1930 the highest chloride values recorded at Poughkeepsie occurred in September, 1949, after one of the driest summers on record. At that time the peak chloride value reached 60 p.p.m., and comparable values persisted for a few days. The average chloride content for the month of September, 1949, was 26 p.p.m. The Sacandaga Reservoir has been of unquestionable value in maintaining fresh water at Poughkeepsie, and recurrence of high salinity under present circumstances is unlikely.

The gradual buildup of chlorides during the summer of 1949 at Poughkeepsie and Chelsea and at Peggs Point, about half-way between, is shown in Figure 5. It will be noted that the high values at Chelsea and Peggs Point fell sharply following a flash storm at the end of August. Then as the stream flow declined, the salt water was again forced upstream. From these data it is also apparent that the salt water did not quite reach Poughkeepsie before the flash runoff. Several days later, after the effects of the storm had worn off, the chlorides were finally pushed as far north as Poughkeepsie.

One can speculate on how high the chlorides might have become at Poughkeepsie if the runoff in September and October had continued as low as during the summer months. Obviously there is some risk and particularly in a community where the Hudson River is the sole source of supply. However, at the end of August, 1949, the Sacandaga Reservoir held 164 billion gallons of usable storage and it is reasonable to assume that releases in the fall would have been increased if necessary.

The effect of the tidal movement on chlorides at Chelsea in September, 1949, is shown in Figure 6. The data are for surface and depth samples on both sides of the river and in the main channel. While the deepest samples generally yielded the highest chlorides, as would be expected, the differences between top and bottom samples are relatively small. The effect of mixing is evident.

In 1949 and 1951 the New York State Health Department conducted surveys of Hudson River water quality between Bear Mountain and Troy. The results of these surveys have been used extensively in the balance of this paper. The 15 sampling points are indicated on Figure 1. The 1949 survey was conducted during the week of August 22-26, three stations being sampled each day. Individual samples were taken from both east and west shores, and at the center of the channel, 5 feet from the top, at middepth, and 5 feet from the bottom.

The 1951 survey was conducted during the months of July, August, September and October. A composite sample was taken at each station three to five times during each month.

The increase in chlorides and hardness between Bear Mountain and Newburgh during the summer of 1951 is shown in Figure 7. The data plotted are the averages of samples at Stations 1, 2, and 3. It will be noted that the chlorides at Station 1 built up rapidly in July and by October reached 600 p.p.m. At Station 2 the maximum value recorded was about 110 p.p.m., and at Station 3 about 70 p.p.m. Station 3 is approximately 20 miles below Poughkeepsie and there was no rise in the chlorides at the Poughkeepsie water works. These data indicate that during an ordinary year such as 1951, the zone separating fresh water and salt water extends over a fairly short distance. At the lower end the increase in chlorides during the summer was rapid; at the upper end the increase was not appreciable.

In concluding that intrusion of salt water is unlikely to increase in the future, it is assumed that the withdrawals of water would be small in relation to river flows, and that most of the water would be returned to the river as sewage or waste to help maintain the fresh water barrier. This condition prevails at Poughkeepsie. It must be kept in mind, however, that if several hundred million gallons a day were diverted from the Hudson River above Poughkeepsie, as was proposed under one plan to serve New York City, the fresh water barrier preventing salt water intrusion would certainly move upstream during periods of low runoff, perhaps with serious consequences. In the case of New York, this difficulty could be met by taking all water from the Catskill and Croton system reservoirs during the relatively short periods that Hudson River water might be brackish. Another possibility would be the matching of withdrawals with greater releases from Sacandaga Reservoir during critical periods. It is certain, however, that if New York City should develop such a project, the State Water Power and Control Commission would require the City to protect the rights of Poughkeepsie and other river water users.

A large part of the total flow during periods of low water discharge is required to maintain the fresh water barrier. To avoid reliance on this barrier and to make possible greater utilization of river flows, it has been proposed to build a regulating dam across the Hudson River near Chelsea. Such a dam would be costly, and because of interference with navigation, flooding of the railroads on both sides of the river, and other complications, it surely would be resisted vigorously. In any event, consideration of such a project is beyond the scope of this paper.

The change in water quality from Troy to Bear Mountain during the dry month, August, 1949, is indicated in Figure 8. These data were obtained by the New York State Health Department survey in that year. The sharp break in chlorides at this time occurred between Station 3 and 4. A month later it had shifted further upstream as indicated by the chloride content of 60 p.p.m. recorded at Poughkeepsie (Figure 5). The color, partly natural and partly due to industrial wastes in the upper Hudson, was fairly constant from Troy to Hyde Park. The gradual decline in color from Hyde Park to the lowest sampling point at Bear Mountain may have been due in part to natural coagulation and bleaching, but probably more to the inflow of low-colored waters from tributaries in the lower part of the Hudson River basin. Conversely, the turbidity rose steadily from Troy to Bear Mountain. These curves represent data taken over only a few days during the summer of 1949. They are representative of low flow summer conditions. Variations from these must be expected at other seasons.

Figure 9 shows the temperature, hardness, alkalinity and color of raw water at Poughkeepsie for each month during 1952 and 1953. It will be noted

from these data that the raw water quality is comparatively uniform with the hardness averaging about 60 p.p.m. and the color ordinarily not much in excess of 25 p.p.m. Figure 9 also shows spot values for the raw water at the Waterford municipal plant on the Hudson River above Troy and for the Winthrop-Stearns plant in Rensselaer. The water at Poughkeepsie is harder than at Waterford, but the color is substantially the same at both places. The alkalinities at Rensselaer and Poughkeepsie are almost equal. The lower alkalinity and hardness at Waterford may be attributed to the soft water normally discharged from the Adirondack Mountains into the upper Hudson River.

Figure 10 shows the average monthly and maximum daily turbidity for each month at Poughkeepsie during the years 1952-53. Noted also on Figure 10 are the maximum values for turbidity at the Winthrop-Stearns plant in Rensselaer and at Waterford. Average values are less than 10 p.p.m. and are not shown. The raw water turbidity at Poughkeepsie is several times greater than at Waterford and Rensselaer.

The effect of sewage pollution on the bacteriological quality of Hudson River water is shown by the curves in Figure 11. Each of these curves represents the results of a series of analyses made by the New York State Health Department in August, 1949, and between July and October, 1951. As should be expected, the coliform density is high in the immediate vicinity of Albany; it declines gradually to Hudson, where there is additional sewage pollution, and then continues to a minimum between Catskill and Hyde Park. This decline in coliform density is due to the bacterial die-away in the stretch of the Hudson River passing through rural communities where the quantity of sewage reaching the river is small. At Poughkeepsie the discharge of raw sewage causes a rapid increase in the coliform density, and high values continue as far south as Newburgh and Beacon. Immediately below Newburgh there is little additional pollution and the effect of bacteria die-away is noted again. It is evident from this profile that the river water a few miles north of Poughkeepsie is much better than is indicated by the City of Poughkeepsie operating data, and that if effective sewage treatment were provided at Albany and Troy, and at the other cities further downstream, the coliform density should be comparatively low throughout the length of the river.

The profile of Figure 11 represents summer conditions, and adequate data are not available for other seasons. At Poughkeepsie, however, the record shows that coliform densities are likely to be greatest during the summer months. The variation in coliform density at the Poughkeepsie water works during the different seasons is shown in Figure 12. The variation at other places may differ, since coliform density at any point is affected by temperature and the time of passage.

Water Use and Treatment

The upper Hudson and Mohawk Rivers are used extensively for industrial water supply purposes with and without treatment.

At the West Virginia Pulp and Paper Company's Mechanicville mill, a 15 m.g.d. supply is taken from the hydroelectric plant forebay and treated for process use. The water is coagulated with alum and filtered in a conventional plant. The process water must be free from turbidity, but moderate color as high as 20 or 30 p.p.m. is not of great importance, and ordinarily not enough coagulant is used to develop a good floc. Except when the river water

is turbid during the spring months, an alum dose of less than 1/2 grain per gallon is sufficient in spite of limited facilities for mixing and coagulation. Laboratory studies have demonstrated that a filtered water with color of less than 10 p.p.m. can be obtained by increasing the alum dose to approximately 2 grains per gallon. Some saving in coagulant is possible by lowering the pH with sulfuric acid. A high-quality low-colored water can be produced at Mechanicville, but until process demands are such as to require it, the cost of additional coagulant is not warranted.

The Waterford municipal plant is 6 miles below the West Virginia Pulp and Paper Company mill at Mechanicville. All of the mills in the upper Hudson valley contribute to the pollution of the river, but the raw water quality at Waterford is affected most directly by the Mechanicville mill. This mill produces sulfite pulp, semi-chemical pulp, and bleached papers. The mill wastes include spent cooking liquors, bleach liquors, and some white water. However, except for occasional difficulties with taste, the raw water at Waterford is amenable to treatment by ordinary methods. The turbidity is low, usually less than 10 p.p.m., and only occasionally more than 30 p.p.m. The color averages between 20 and 30 p.p.m. As previously noted, regulation of Hudson River flows by Indian Lake and the Sacandaga Reservoir and operation of mill ponds in the river above Waterford affect the water quality. In general, the quality has been more uniform since 1930, and extreme values for color and alkalinity are less frequent.

A considerable volume of untreated sewage is discharged into the Hudson River from the many towns above Waterford. The mill wastes (particularly bleach wastes) may reduce bacteriological pollution to some extent. Throughout 1953 the plate counts in the raw water at Waterford normally ranged from 150 to 1,000 per milliliter (37°C.), and the coliform density was 2,400 per 100 ml. or higher.

The water treatment at Waterford consists of coagulation, sedimentation, rapid sand filtration and effluent aeration (except when aeration is prevented by freezing weather). No mixing or flocculating equipment was included in the original plant construction, but compressed air is now applied at the inlet end of the settling basins. The basins provide a total of 2 hours for mixing and sedimentation at normal operating rates. Chlorine is applied to the water as it leaves the settling basins because it was found that application ahead of the alum interfered with coagulation.

During 1953 the average alum dose ranged from about 2 grains per gallon in January and February to about 2.75 grains per gallon in the late fall. Soda ash or lime are used to adjust the pH after treatment. The prechlorine dose during the winter ranged from 1.2 to 1.8 p.p.m. In the summer when the most severe taste difficulties were encountered, the chlorine dose was increased to approximately 15 p.p.m. Chemical costs ranged from about $15 per million gallons during the winter months to a maximum of $35 per million gallons in September. The plant is small and chlorine is purchased in 150-pound cylinders; the summer increase in chemical costs would be considerably less at a large plant where chlorine probably would be purchased in ton containers.

The water works at the Winthrop-Stearns pharmaceutical plant at Rensselaer produces a high quality water for cooling and other process purposes. However, City water after further treatment is used in the products themselves. The raw water is subject to pollution by concentrated discharges of sewage into the Hudson River above and below the intake. The natural color of the water is low, but periodic discharges of dye-plant waste from

other outfalls in the vicinity imparts a high color to the raw water. This color is not easily removed, but fortunately is of no great consequence in the uses to which the water is put.

The treatment provided at Winthrop-Stearns includes prechlorination, coagulation, rapid sand filtration, and postchlorination. The plant was designed for a nominal capacity of 5 m.g.d. (3,500 g.p.m.), but is normally operated intermittently at a rate of 2,500 g.p.m. to meet water requirements.

Coagulation and sedimentation are obtained in an "upflow" or "sludge contact" type basin. The basin has a total capacity of 200,000 gallons and provides a total mixing and settling time of 1 hour and 20 minutes when the flow through the plant is 2,500 gallons per minute. The basin is followed by a second tank which serves as a secondary settling or detention basin. This second tank is of the same size and dimensions as the first but does not include mixing equipment or baffles. Evidently the second tank was included so that it could be converted into a coagulation basin at a later date if expansion proved necessary. The second tank provides extra contact time after prechlorination, but otherwise does not affect the plant operation substantially. The rapid sand filters are of conventional design.

The prechlorination dose ranges from 1 to 13 p.p.m. depending upon the chlorine demand of the raw water. A chlorine residual is carried through the plant, and a 0.2 p.p.m. residual is maintained in the effluent by postchlorination, if necessary. Some changes in chemical treatment have been made in recent months, but the plant was operated for several years with an alum dose ranging from 2 to 2-1/2 grains per gallon. Sulfuric acid was added in the amount of 0.7 to 1.0 grain per gallon in order to obtain optimum pH for flocculation, about 5.6 to 5.9. Activated silica has been added to the water on a continuous basis at 2 to 8 p.p.m. to promote floc formation with a reasonable coagulant dosage. Ground limestone has also been employed recently and permits the use of less activated silica. The turbidity of the settled water going to the filters is normally low. Some of the filters have sand as media, and some have anthrafilt. In general, the anthrafilt yields filter runs twice as long as the sand. In the summertime sand filter runs are approximately 75 hours; in the winter from 35 to 40 hours.

This plant is of particular interest because it demonstrates the suitability of the "upflow" or "sludge contact" type of basin for use on extremely cold water. During the winter months the water temperature is only slightly above freezing. Coagulation is not as good in the winter months as in the summer, but results have been satisfactory. However, this type of basin requires a constantly heavy coagulant dose in order to maintain a floc that will settle and not carry over to the filters. Where conventional horizontal flow basins are used, it is sometimes possible to reduce the coagulant dose under favorable conditions.

The municipal plant at Rensselaer a short distance north of the Winthrop-Stearns plant takes its water from the Hudson River. The plant was built prior to 1914 and consists of horizontal flow settling tanks and wood tub filters. The water is coagulated with alum and chlorinated. The raw water is badly polluted at Rensselaer, and an upland supply has been under consideration for many years.

The Cohoes municipal plant takes water from a power company feeder canal on the Mohawk River. Water passes first through a raw water reservoir providing 7 to 10 days' storage and then through a conventional rapid sand filter plant with horizontal flow basins. The water is coagulated with alum and chlorinated. A new source of supply has been proposed for Cohoes,

but no final decision has been reached.

The Poughkeepsie water works were built in 1872. Construction of the plant followed several years of debate regarding the relative merits of the Hudson River and upland sources of supply. The Hudson River was decried because of sewage pollution and because somewhat brackish water had been known to reach Poughkeepsie during periods of low flow, especially following a persistent wind from the south. Professional opinion was decidedly in favor of an upland supply, but the City authorities decided otherwise. (In 1914 the desirability of abandoning the river works for an upland supply was investigated, but no action taken.)

The original plant at Poughkeepsie was designed by J. P. Kirkwood, the "father of slow sand filtration in America," along the lines of early English filters. The plant consisted of a small inlet basin and two open slow sand filters, each with an area of 1/3 acre. In 1896 two more filters were added, making a total filter bed area of 1-1/3 acres. The filters were covered in 1906, and a 3-million-gallon coagulating and settling basin with wooden baffles was built in 1907. Coagulant has been used intermittently until 1929, and continuously since that time. In 1920 the plant capacity was increased by the construction of a 4 m.g.d. prefilter ahead of the slow sand filters. (The prefilter is similar to a conventional rapid sand filter except that relatively coarse sand is used. It removes much of the turbidity and makes possible operation of the slow sand filters at higher rates.) At the same time an aerator was installed in the original inlet basin between the new prefilter and the slow sand filters. In 1928 the prefilter capacity was doubled. Major improvements at Poughkeepsie since 1928 have included the construction of a new intake in 1945-46, the installation of large pumps and piping, and rehabilitation of the four slow sand filters to permit operation at higher rates.

The original intake, built in 1872, extended only 100 feet offshore into water approximately 20 feet deep. The intake was subject to pollution from city sewage carried upstream on the flood tide, and from sewage discharged from the Hudson River State Hospital into the river 2,000 feet upstream. Until the State Hospital sewage treatment plant was built in 1933, and even after that time to a lesser degree, the Poughkeepsie raw water intake was dangerously located.

Bacteriological tests in 1939 showed that an intake 1,000 feet to 1,500 feet long would clear the pollution along the eastern shore and would avoid pollution by the Poughkeepsie sewage carried upstream during high tide. The coliform density in the vicinity of Poughkeepsie at high and low tides in 1939 is indicated by Figure 13. Preliminary studies for a new intake were made in 1941, but because of the war construction was not attempted until 1945, when a break in the old intake required immediate action. The new intake, finished in 1946, extends 1,000 feet into the main channel of the river, where the water is approximately 50 feet deep. The coliform density in the raw water dropped immediately when the new intake was put into service.

The raw water at Poughkeepsie is certainly not as good as an impounded water from unpolluted streams, and perhaps the City has reason to regret that an upland supply was not developed years ago when suitable sites were available. However, the Hudson River supply is far better than it is often characterized. Frequency plottings of the monthly average turbidity and coliform density in the raw water at several plants in the United States are shown in Figures 14 and 15. For the most part, the data shown are based upon three- and four-year records extending back to 1950 or 1951. It will be noted from these data that the Hudson River at Poughkeepsie compares fairly

well with the sources cited.

The piping changes, installation of pumps, and rehabilitation of the slow sand filters have all been directed toward increasing the safe output of the plant. The average daily water demand has increased from 4.4 m.g.d. in 1941 to 7.0 m.g.d. in 1953, and peak requirements have grown even more rapidly. Rehabilitation of the last of the four filters is nearly finished. The rehabilitation program has included the construction of a control chamber, the installation of larger underdrains, and washing the fines out of the sand to obtain an effective size between 0.4 and 0.45 mm. Upon completion of this work and minor piping changes, it is estimated that the plant can produce 10 m.g.d. with occasional peak operation as high as 12 m.g.d. At such rates the loading on the slow sand filters will be between 7-1/2 and 9 m.g.d. per acre.

The treatment at Poughkeepsie consists of prechlorination, coagulation with alum, prefiltration, aeration, slow sand filtration, pH control with lime and postchlorination when necessary. (The water is also fluoridated.) The maximum, minimum, and average chemical requirements and chemical costs during 1953 were as follows:

1953 Chemical Dosages

	Maximum	Minimum	Average	Ave. Cost per m.g.
Alum, grains/gal.	3.86	0.91	1.84	
lbs./m.g.	550	130	263	$6.00
Prechlorination, p.p.m.	8.9	2.7	5.6	
lbs./m.g.	74	23	47	4.47*
Postchlorination, p.p.m.	0.37	0	0.13	
lbs./m.g.	3.1	0	1.1	.10
Lime for pH correction				
grains/gal.	0.8	0.4	0.57	
lbs./m.g.	111	54	81	.92
				$11.49

Alum - $45.60 per ton
Lime - $22.75 per ton
Chlorine - 9-1/2¢ per lb.

*Installation of facilities for using ton containers will reduce the chlorine cost by $1.50 or more.

The character of the water as it passes through the plant is shown in the data on the following page taken from the 1953 operating reports.

The finished water at Poughkeepsie is free from color and turbidity. It does not have the taste of a mountain spring, but breakpoint chlorination in recent years has eliminated serious taste troubles. The water is somewhat harder than that obtained from most impounded supplies in eastern New York State, but the hardness of 75 p.p.m. compares closely with the average of 78 p.p.m. for 45 of the larger municipal supplies in the State.

The coagulation and sedimentation facilities at Poughkeepsie leave much to be desired, and occasionally floc passes through the prefilters. The principal deficiency is the absence of means of cleaning the basin regularly and rapidly. The basin has only a single small drain at the center, and must be taken out of service periodically in order to remove sludge. As the demand

1953 Water Quality

		Raw	Settled	Prefiltered and Aerated	Filtered (After pH Correction)
		parts per million			
Alkalinity, as $CaCO_3$,	Max.	70	59	56	72
	Min.	40	27	25	37
	Ave.	54	38	38	50
Hardness, as $CaCO_3$	Max.	--			88
	Min.	--			60
	Ave.	61			75
Color	Max.	30	7	4	0
	Min.	15	3	0	0
	Ave.	21	4	0.2	0
pH	Ave.	7.1	6.5	--	7.9

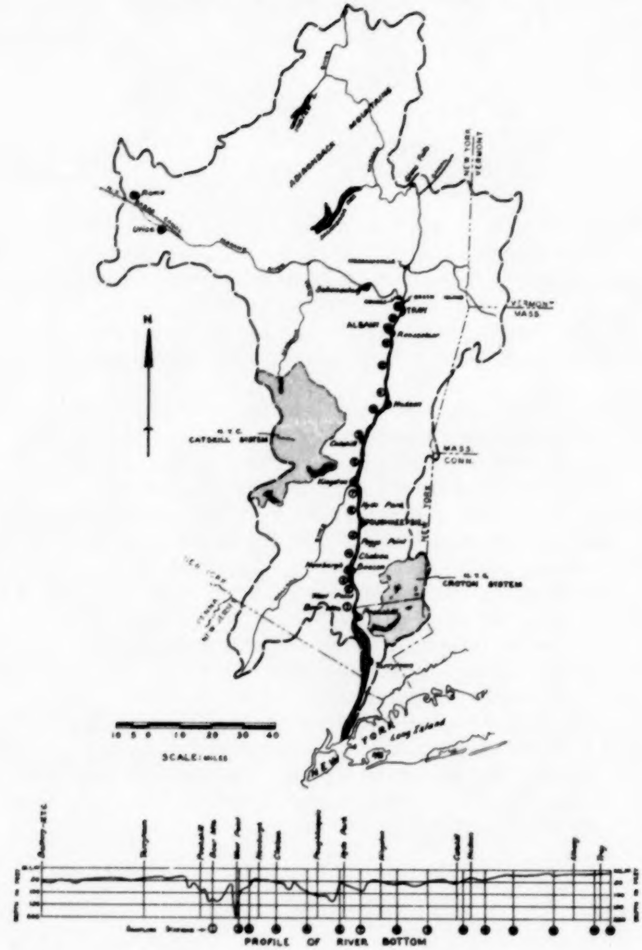
for water has increased, it has become increasingly difficult to take the basin out of service for a period long enough to do this. As a result, the effective settling capacity is sometimes less than half the total basin volume, and turbid water is delivered to the prefilters. However, in spite of inadequate pretreatment, the free chlorine residual in the basin assures a prefilter effluent that meets U.S. Public Health Service standards practically all of the time.

The prefilters were installed many years ago to reduce the turbidity and load on the slow sand filters and to increase the capacity of the plant. The prefilters were not added because double filtration was needed to produce a safe water. The slow sand filters provided excellent protection against possible failure of coagulation and chlorination. Chlorine was used sparingly in those days, and there was no thought of trying to carry a chlorine residual throughout the plant, particularly on to the slow sand filters. Under present methods of operation, the plant provides a contact time of about 12 hours for the chlorine to act, and complete disinfection is almost certain. At the same time chlorination of the raw water yields a stable sludge free from taste and odor-producing substances. Without prechlorination it would have been impossible to operate the overloaded basin in recent years.

Experience at Poughkeepsie and elsewhere indicates that a conventional modern rapid sand filter plant and adequate chlorination will yield a safe and satisfactory water from the Hudson River. The situation should be even better in the future when the construction of sewage and waste treatment plants has improved the quality of raw water.

FIGURE 1

HUDSON RIVER DRAINAGE BASIN



PROFILE OF RIVER BOTTOM

FIGURE 2

HUDSON RIVER AT MECHANICVILLE

MEAN ANNUAL FLOWS AND
5-YEAR RUNNING AVERAGE

1887-1953

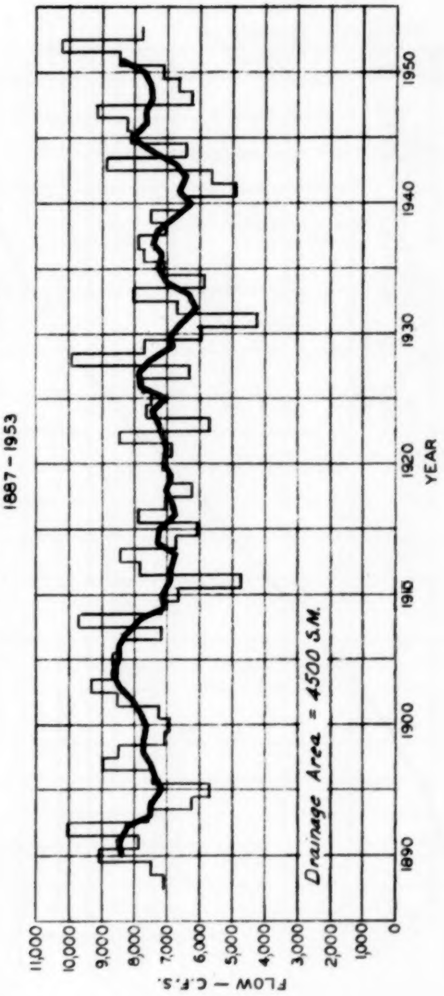


FIGURE 3

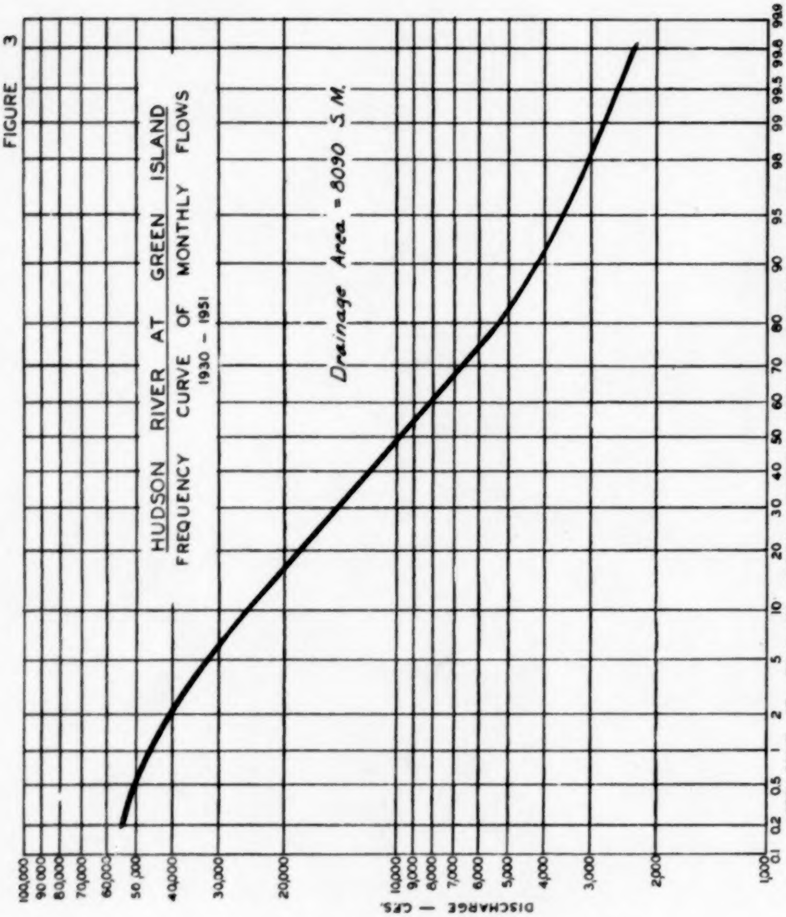

HUDSON RIVER AT GREEN ISLAND
FREQUENCY CURVE OF MONTHLY FLOWS
1930 - 1951
Drainage Area = 8090 S.M.
DISCHARGE — C.F.S.
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9
PER CENT OF TIME IN WHICH MONTHLY AVERAGE DISCHARGE IS EQUAL TO OR MORE THAN STATED MAGNITUDE

FIGURE 4

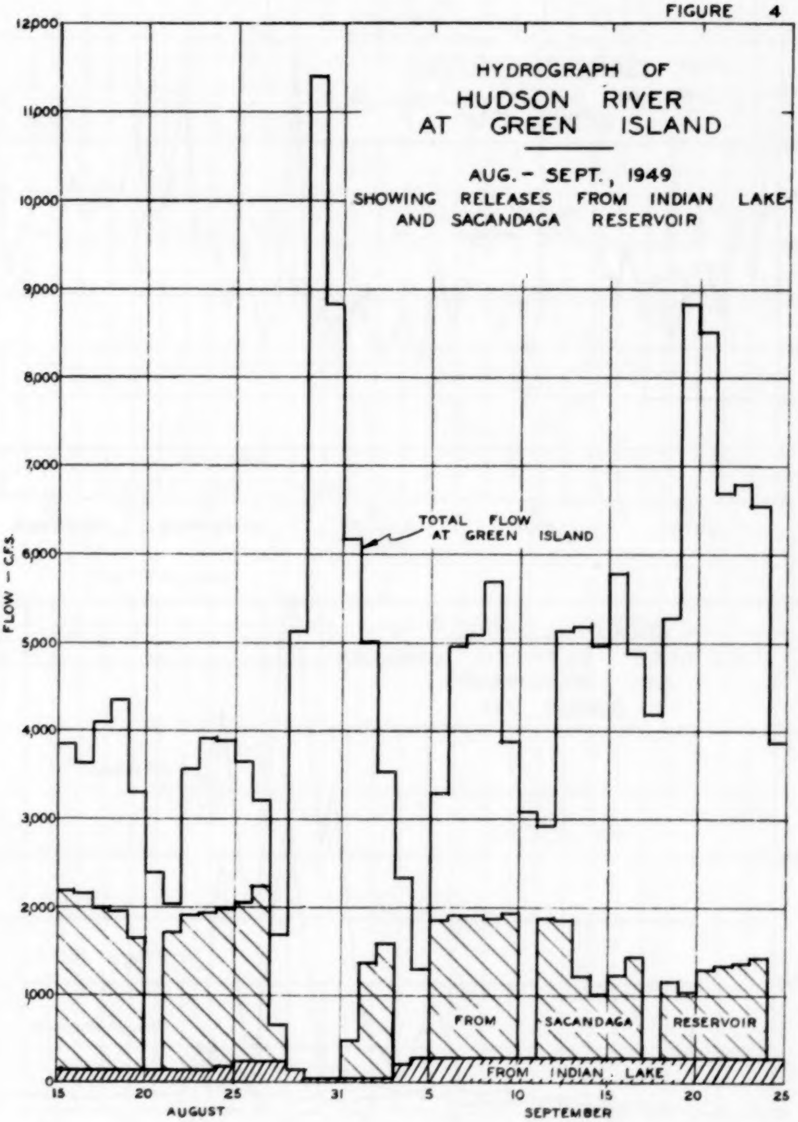
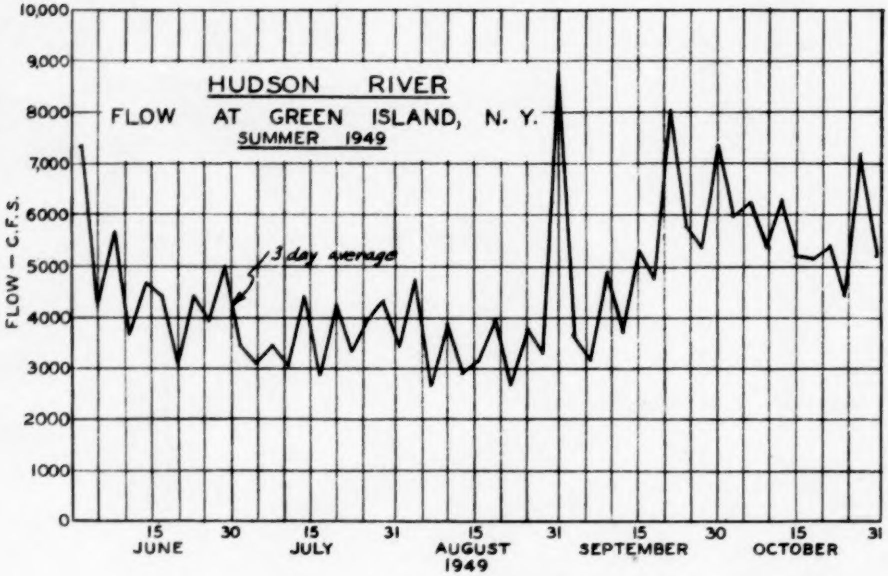

HYDROGRAPH OF
HUDSON RIVER
AT GREEN ISLAND
AUG. - SEPT., 1949
SHOWING RELEASES FROM INDIAN LAKE
AND SACANDAGA RESERVOIR
TOTAL FLOW
AT GREEN ISLAND
FROM SACANDAGA RESERVOIR
FROM INDIAN LAKE
FLOW - C.F.S.
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
15 20 25 31 5 10 15 20 25
AUGUST
SEPTEMBER

FIGURE 5


HUDSON RIVER
FLOW AT GREEN ISLAND, N. Y.
SUMMER 1949
FLOW — C.F.S.
10,000
9,000
8000
7,000
6000
5000
4000
3000
2000
1000
0
3 day average
15
30
31
15
31
15
31
15
30
15
31
JUNE
JULY
AUGUST
1949
SEPTEMBER
OCTOBER

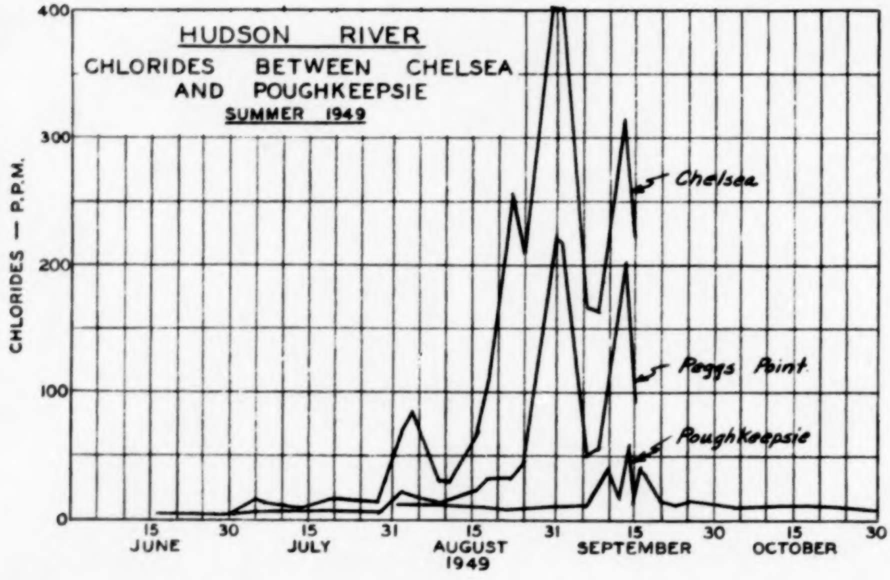

HUDSON RIVER
CHLORIDES BETWEEN CHELSEA AND POUGHKEEPSIE
SUMMER 1949
CHLORIDES — P.P.M.
400
300
200
100
0
Chelsea
Roggs Point
Poughkeepsie
15
30
15
31
15
31
15
30
15
30
JUNE
JULY
AUGUST
1949
SEPTEMBER
OCTOBER

FIGURE 6

HUDSON RIVER AT CHELSEA

TIDAL EFFECT ON CHLORIDES DURING LOW FLOW PERIOD — SEPT. 1949

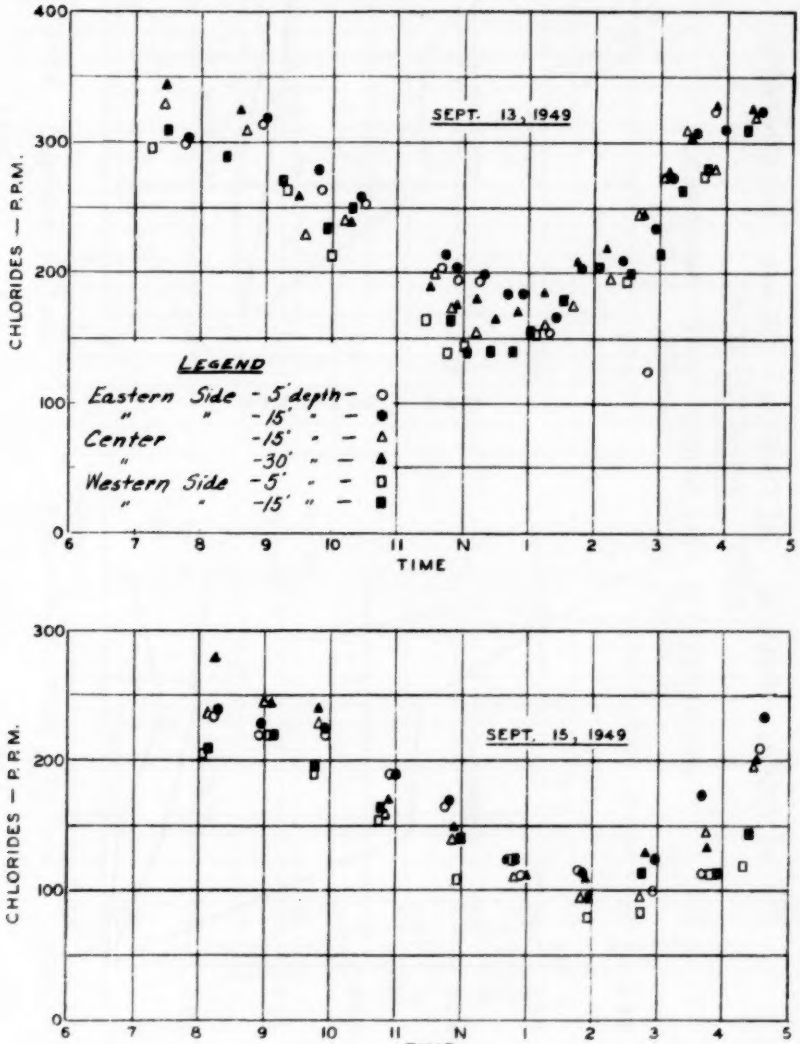


FIGURE 7

HUDSON RIVER BETWEEN BEAR MOUNTAIN AND NEWBURGH

INCREASE IN CHLORIDES AND HARDNESS DURING LOW SUMMER FLOWS

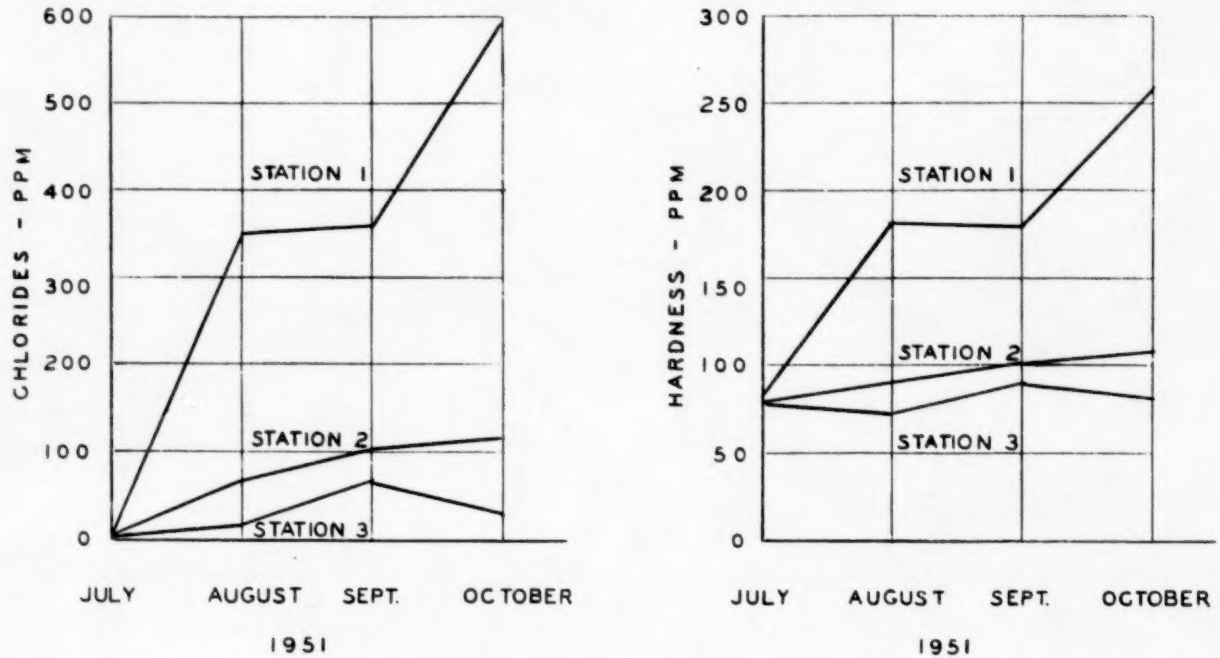
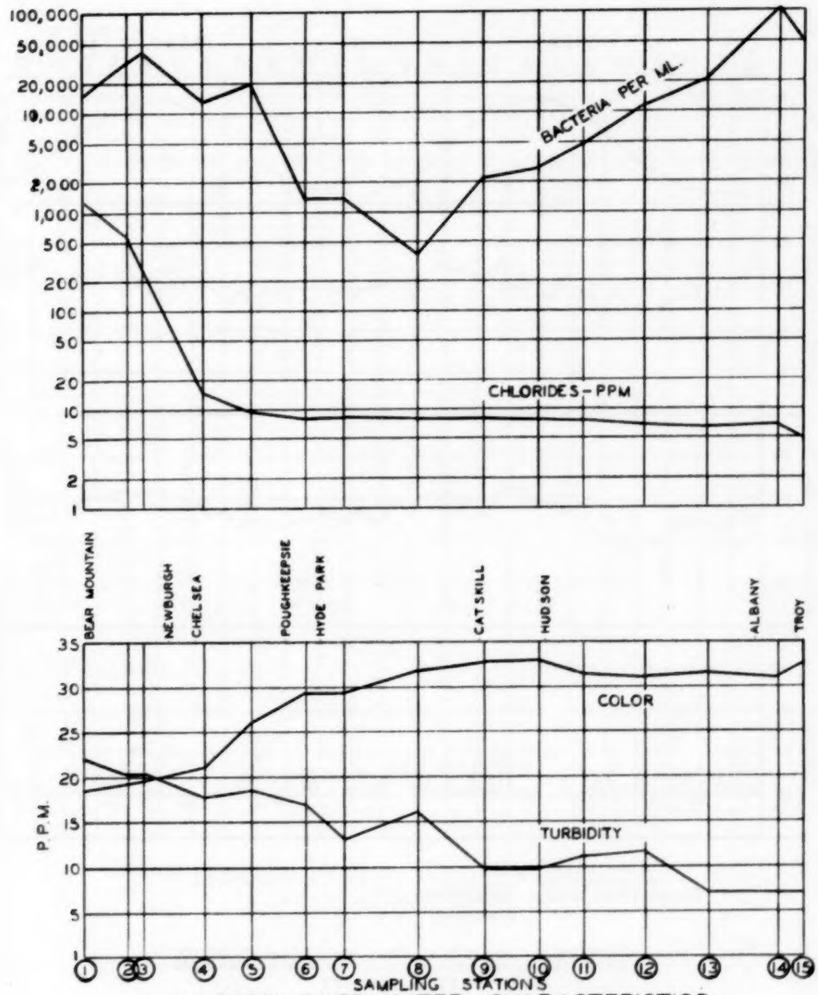
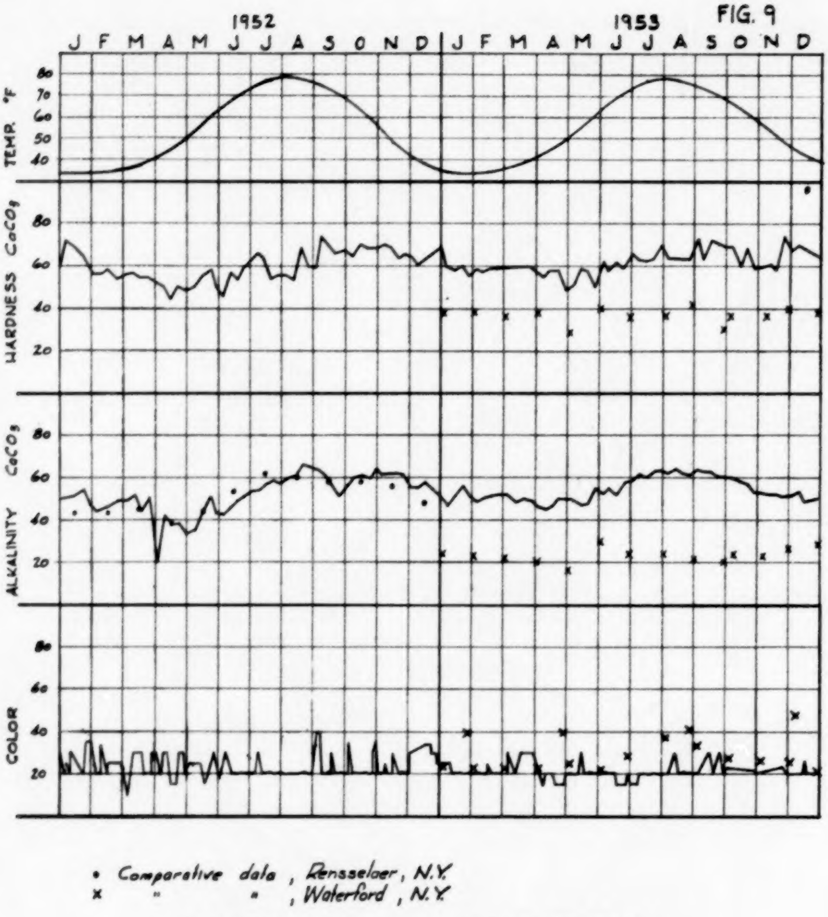


FIGURE 8



HUDSON RIVER WATER CHARACTERISTICS
DURING PERIOD OF LOW RUNOFF
AUGUST, 1949

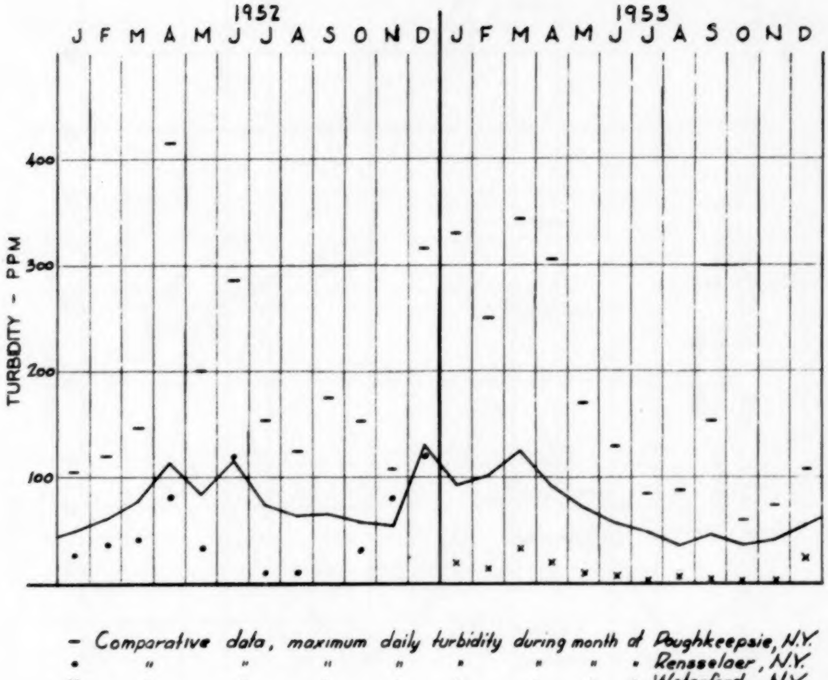


HUDSON RIVER AT POUGHKEEPSIE

RAW WATER QUALITY

1952 — 1953

FIG. 10



HUDSON RIVER AT POUGHKEEPSIE

MONTHLY AVERAGE TURBIDITY

1952 — 1953

FIGURE 11

COLIFORM DENSITY OF HUDSON RIVER WATER

DURING SUMMER MONTHS

1949 – 1950

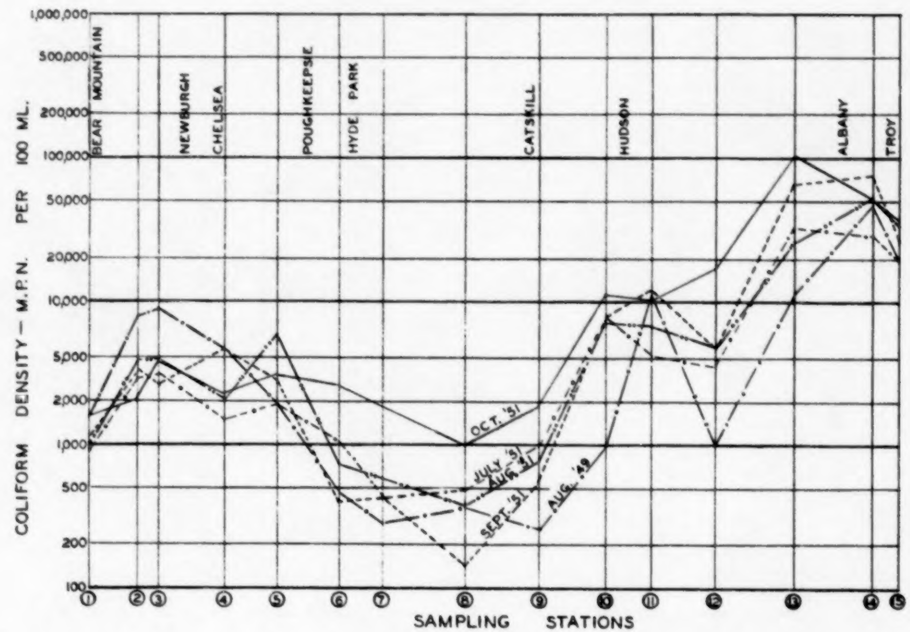


FIGURE 12

MONTHLY AVERAGE
COLIFORM DENSITY OF POUGHKEEPSIE RAW WATER
1949 – 1953

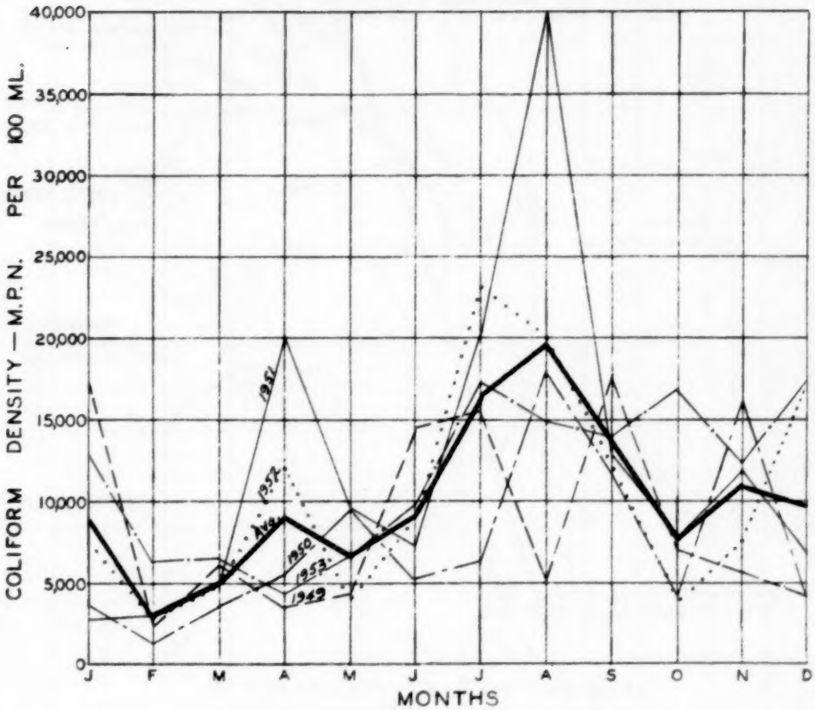
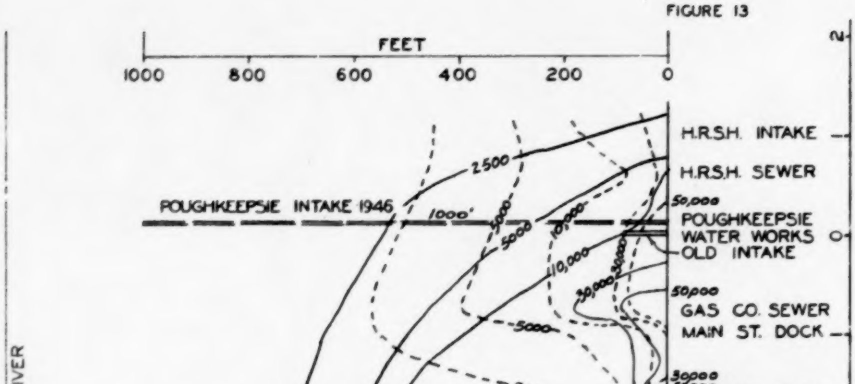


FIGURE 13

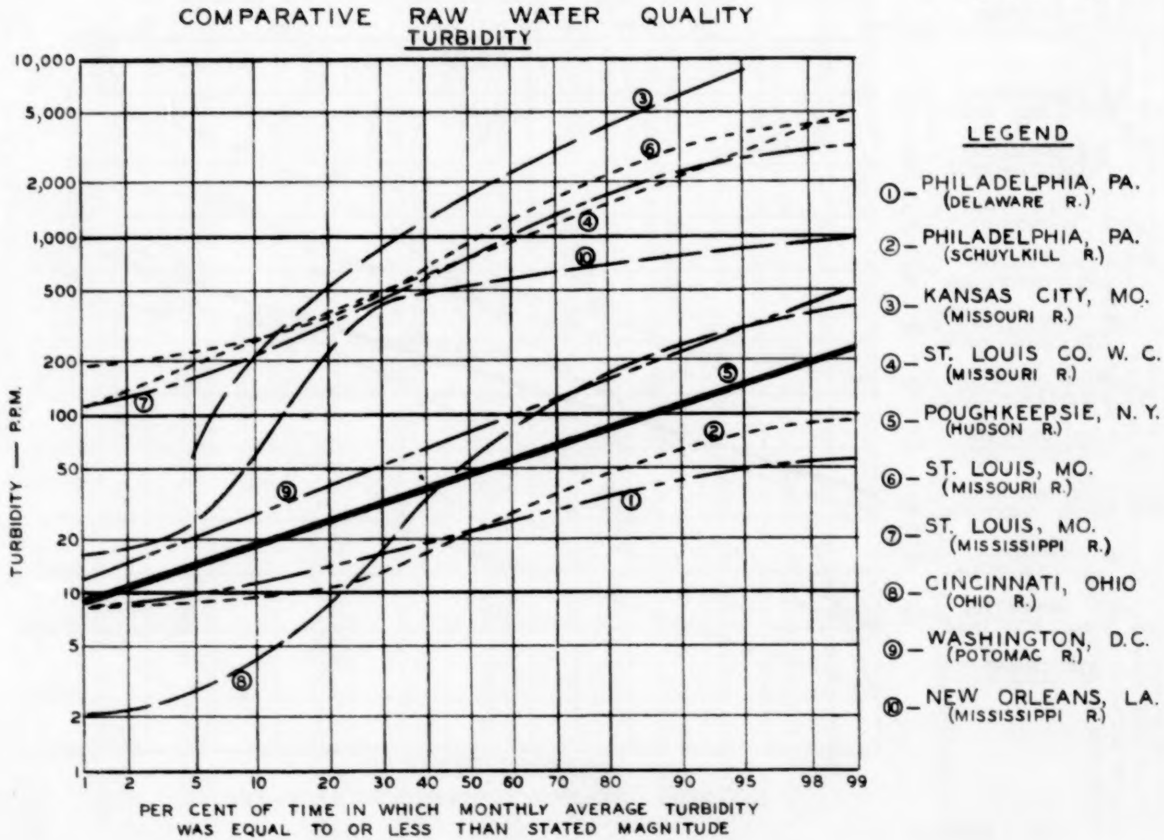


HUDSON RIVER AT POUGHKEEPSIE

EFFECT OF TIDE ON COLIFORM DENSITY

REF. N.Y. STATE DEPT. OF HEALTH

FIGURE 14

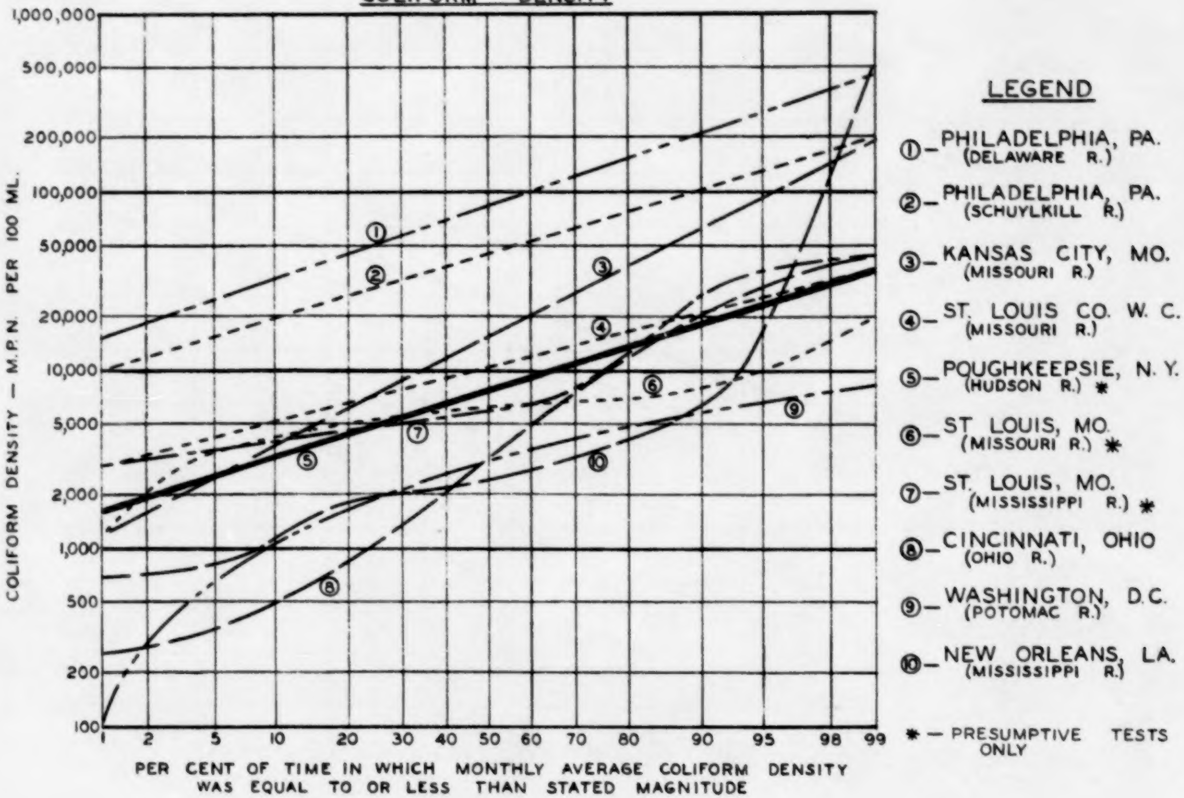


COMPARATIVE RAW WATER QUALITY
TURBIDITY
TURBIDITY — P.P.M.
10,000
5,000
2,000
1,000
500
200
100
50
20
10
5
2
1
1 2 5 10 20 30 40 50 60 70 80 90 95 98 99
PER CENT OF TIME IN WHICH MONTHLY AVERAGE TURBIDITY WAS EQUAL TO OR LESS THAN STATED MAGNITUDE
LEGEND
① – PHILADELPHIA, PA. (DELAWARE R.)
② – PHILADELPHIA, PA. (SCHUYLKILL R.)
③ – KANSAS CITY, MO. (MISSOURI R.)
④ – ST. LOUIS CO. W. C. (MISSOURI R.)
⑤ – POUGHKEEPSIE, N. Y. (HUDSON R.)
⑥ – ST. LOUIS, MO. (MISSOURI R.)
⑦ – ST. LOUIS, MO. (MISSISSIPPI R.)
⑧ – CINCINNATI, OHIO (OHIO R.)
⑨ – WASHINGTON, D.C. (POTOMAC R.)
⑩ – NEW ORLEANS, LA. (MISSISSIPPI R.)

FIGURE 15

COMPARATIVE RAW WATER QUALITY

COLIFORM DENSITY



PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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MARCH: 414(WW)[d], 415(SU)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

MAY: 435(SM), 436(CP)[c], 437(HY)[c], 438(HY), 439(HY), 440(ST), 441(ST), 442(SA), 443(SA).

JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.